

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 2010		2. REPORT TYPE		3. DATES COVERED 00-00-2010 to 00-00-2010	
4. TITLE AND SUBTITLE Combined Spectroscopic and Interferometric (NPOI) Observations of the Be Star o Cassiopeiae				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) US Naval Observatory,Flagstaff Station,10391 W Naval Obs. Road,Flagstaff,AZ,86001				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT see report					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 2	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

COMBINED SPECTROSCOPIC AND INTERFEROMETRIC (NPOI) OBSERVATIONS OF THE Be STAR α CASSIOPEIAE

P. Koubský,¹ C. Hummel,² P. Harmanec,³ S. Yang,⁴ H. Božić,⁵ C. Tycner,⁶ and R. Zavala⁷

RESUMEN

El análisis de las velocidades radiales de la estrella α Cas de los espectros tomados entre 1992 y 2008 en Ondřejov y Dominion Astrophysical Observatory nos permitieron reconfirmar la naturaleza binaria de este objeto, primeramente sugerida por Abt & Levy en 1978, y más tarde refutada por varios autores. Los parámetros orbitales de este sistema SB1 implican una función de masa muy alta de alrededor de una masa solar. Esto implica una masa muy alta de la estrella secundaria, posiblemente mayor que la de la estrella primaria. Para comprobar si hay la existencia de una secundaria tan masiva, α Cas fue observada con el interferómetro óptico de prototipo de la marina, el cuál permitió resolver espacialmente por primera vez ambas componentes binarias. Las observaciones interferométricas condujeron a la detección de una secundaria, cerca de 3 magnitudes más débil que la primaria. Se discuten las posibles características de este sistema binario peculiar.

ABSTRACT

The analysis of radial velocities of the Be star α Cas from spectra taken between 1992 and 2008 at Ondřejov and Dominion Astrophysical Observatories allowed us to reconfirm the binary nature of this object, first suggested by Abt and Levy in 1978, but later refuted by several authors. The orbital parameters of this SB1 system imply a very high mass function of about one solar mass. This in turn leads to a very high mass of the secondary, possibly higher than that of the primary. In order to check for the existence of such a massive secondary, α Cas was observed with the Navy Prototype Optical Interferometer, which allowed the binary components to be spatially resolved for the first time. The interferometric observations lead to the detection of a secondary, about 3 mag fainter than the primary. The possible properties of this peculiar binary system are discussed.

Key Words: astrometry — binaries: spectroscopic — stars: emission-line, Be

1. GENERAL

α Cas (HD 4180, HR 193) is a bright Be star ($V=4^m.3-4^m.6$ var., $B-V = -0^m.03$, $U-B = -0^m.59$, B5IIIe, $v \sin i = 220 \text{ km s}^{-1}$). α Cas is a typical Be star which shows: (i) long-term changes from absorption to emission in H α line and back (Peton 1971; Hubert-Delplace & Hubert 1979), (ii) correlation between star brightness and strength of H α emission (Koubský et al., in preparation), (iii) variations of radial velocity (Abt & Levy 1978; Koubský

et al. 2004), and (iv) short-term photometric variability (Hubert & Floquet 1998).

2. RADIAL-VELOCITY VARIATIONS: BINARY OR LONG-TERM CHANGES?

Using He I absorption RVs from 20 photographic spectra, Abt & Levy (1978) – (AL) proposed that α Cas is a single-line spectroscopic binary with an orbital period of 1033 days. Harmanec (1987) showed that available RVs could be folded with various periods and suggested that the star should not be considered a spectroscopic binary. He suspected that the RV curve derived by AL was a manifestation of long-term variations known for number of other Be stars. Koubský et al. (2004) secured more spectra of α Cas with better S/N and showed that the RV variations were *indeed* due to orbital motion, but were unable to explain why the lines of the secondary, probably more massive than the primary, were unseen.

3. RESULTS FROM SPECTROSCOPY, PHOTOMETRY AND INTERFEROMETRY

Here we report results of our α Cas study which started in 2004. We collected about 400 high S/N

¹Astronomical Institute AS CR, 251 65 Ondřejov, Czech Republic (koubsky@sunstel.asu.cas.cz).

²ESO, Karl-Schwarzschild-Strasse 2, 85748 Garching bei München, Germany (chummel@eso.org).

³Astronomical Institute of the Charles University, Faculty of Mathematics and Physics, V Holešovičkách 2, 180 00 Praha 8, Czech Republic (hec@sirrah.troja.mff.cuni.cz).

⁴Physics & Astronomy Department, University of Victoria, PO Box 3055 STN CSC, Victoria, BC, V8W 3P6, Canada (yang@uvastro.phys.uvic.ca).

⁵Hvar Observatoty, Faculty of Geodesy, Kačićeva 26, 10000 Zagreb, Croatia (hbozic@geof.hr).

⁶Department of Physics, Central Michigan University, Mt. Pleasant, MI 48859, USA (tycne1c@cmich.edu).

⁷US Naval Observatory, Flagstaff Station, 10391 W. Naval Obs. Rd., Flagstaff, AZ 86001, USA (bzavala@nobs.navy.mil).

TABLE 1
ELEMENTS OF α CAS FROM SPECTROSCOPY
AND INTERFEROMETRY

Element	Solution
P (d)	1031.03 ± 0.70
$T_{\text{RV max}}$	51760.5 ± 1.4
K (km s^{-1})	21.597 ± 0.068
rms (km s^{-1})	0.940 (one measurement)
a (mas)	17.1
Ω ($^\circ$)	274.5
i ($^\circ$)	115
e	0
$F(m)$ (M_\odot)	1.076

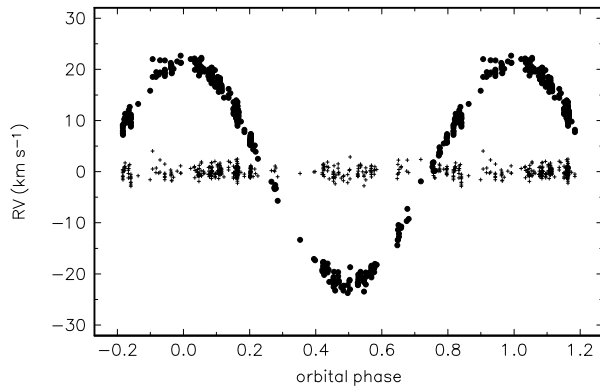


Fig. 1. A phase diagram for the 1031-d period. The RV's were measured on the steep wings of the $H\alpha$ emission line and prewhitened for the long-term changes. The O-C deviations are plotted as small crosses.

spectra, measured them for radial velocity, and derived new elements using the code FOTEL (Hadrava 2004). The elements are in the upper part of Table 1, while the phase diagram is in Figure 1. From the compiled measurements of $H\alpha$ emission strength and UBV photometry we concluded that the correlation luminosity/strength of $H\alpha$ emission suggests (according to Harmanec 1983) that the envelope is seen under a low angle.

Definitive proof of the duplicity of α Cas came from observations with the Navy Prototype Optical Interferometer (NPOI), which resolved two components in the visual with a magnitude difference of $\Delta m_V = 2.9$ mag. Orbital motion consistent with the spectroscopic period of 1031 d was subsequently de-

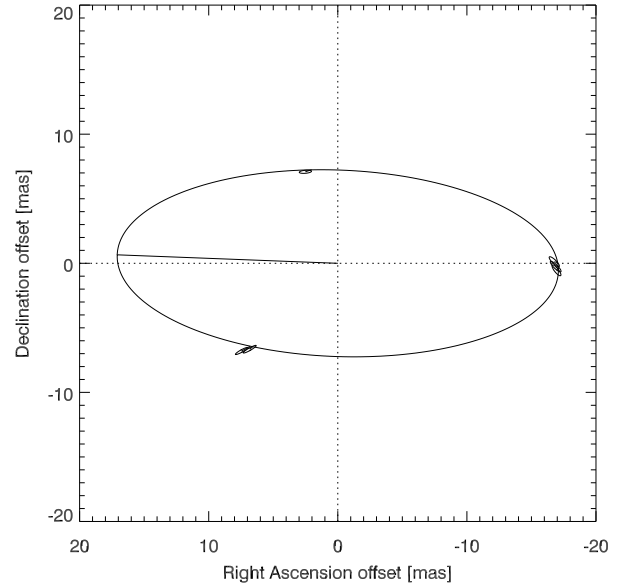


Fig. 2. Visual orbit of α Cas. Note that the NPOI results suggest that the inclination angle between the normal to the orbital plane and the line-of-sight is much higher than the suspected inclination of the envelope.

tected by NPOI, and a preliminary orbit fitted to the relative astrometry and the RV curve is shown in Figure 2, adopting an orbital eccentricity of zero. These results are consistent with the elements describing the motion of the photo-center determined by Jancart et al. (2005) from Hipparcos data.

NPOI observations also detected a drop of the visibility in a channel centered on the $H\alpha$ line. This is interpreted as an extended line emission component, with a Gaussian width of 1.8 mas. The shape is roughly circular.

REFERENCES

- Abt, H., & Levy, S. G. 1978, *ApJS*, 36, 241
- Hadrava, P. 2004, *Publ. Astron. Inst. Acad. Sci. Czech Rep.*, 92, 1
- Harmanec, P. 1983, *Hvar Observatory Bull.*, 7, 55
- . 1987, *Bull. Astron. Inst. Czechosl.*, 38, 283
- Hubert, A. M., & Floquet, M. 1998, *A&A*, 335, 565
- Hubert-Delpace, A. M., & Hubert, H. 1979, *An Atlas of Be Stars* (Paris: Meudon Observatory)
- Jancart, S., Jorissen, A., Babusiaux, C., & Pourbaix, D. 2005, *A&A*, 442, 365
- Koubský, P., Ak, H., Harmanec, P., Yang, S., & Božić, H. 2004, *ASP Conf. Ser.* 310, *Variable Stars in the Local Group*, ed. D. W. Kurtz & K. R. Pollard (San Francisco: ASP), 387
- Peton, A. 1972, *A&A*, 18, 106